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My name and post office address are as stated below;

That I am knowledgeable in the German language in which the below identified international application was filed, and that, to the best of my knowledge and belief, the English translation of the international application No. PCT/DE2003/003954 is a true and complete translation of the above identified international application as filed.

I hereby declare that all the statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the patent application issued thereon.

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## Description

Method and apparatus for filling material separations at a surface

The invention relates to a method and an apparatus for filling material separations in accordance with the preamble of claims 1 and 17, respectively.

Material separations at an inner and/or outer surface of a component - for example comprising a substrate or a layer - such as for example cracks, drilled holes or manufacturing-related, operationally induced notches, often have to be closed up again by welding or soldering processes. These methods use high temperatures in the vicinity of the material separation which is to be filled, leading to thermal stresses in the substrate/layer of a component, which can lead to cracks. The material which is used in the welding or soldering processes to fill the material separation often has a considerably reduced mechanical strength compared to the material of the substrate, with the result that the ability of the component to be repaired is limited.

Therefore, it is an object of the invention to provide a method and an apparatus for filling material separations in which the abovementioned drawbacks are overcome.

The object is achieved by a method and an apparatus in accordance with claims 1 and 17, respectively.

Further advantageous refinements of the method and apparatus according to the invention are listed in the subclaims.

Exemplary embodiments are shown in the figures, in which:

Figure 1 shows an apparatus which is used to carry out the method according to the invention,

Figure 2 shows a crack which is filled in steps, and

Figure 3 shows a time profile for a current between substrate and electrode,

Figure 4 shows a further time profile for a current between substrate and electrode, and

Figure 5 shows a widened material separation.

Figure 1 shows an apparatus 40 according to the invention which is used to carry out the method according to the invention. Material is introduced into a material separation 4 in a substrate 1 or a layer 1 extending from a surface 2 in an electrolytic process at low temperatures, for example lower than 100°C.

The substrate 1 with its material separation 4 is electrically connected to an electrode 7, which together are arranged in an electrolyte 10 which is present in a vessel 46. There is an electric voltage source 25 between the electrode 7 and the substrate 1, so that an electric current can flow.

The electrolyte 10 contains the material which is introduced into the material separation 4. The solution of the electrolyte 10 may include constituents of the composition of the substrate 1 in the form of particles and/or ions.

The process of the method according to the invention can take place at room temperature or low temperatures, which means that prior to use of the method according to the invention the substrate 1 can have a suitable mask (waxes,

polymers) applied to it in a simple way at the locations at which coating is not desired, and can thus be protected against being coated.

The use of a flow of current which varies over the course of time makes it possible to effect targeted deposition of the constituents, for example an alloy, from the electrolyte 10 into the material separation 4 of the component 1.

Required materials properties can be set, for example, by a subsequent heat treatment, as is necessary, for example, for nickel-base and cobalt-base superalloys for turbine blades and vanes in order to obtain the desired  $\gamma$ - $\gamma'$  precipitations or to achieve a phase change or phase adjustment.

The deposition of material of the same or a similar type to the material of the substrate 1, in the form of particles and/or ions, results in a significantly improved strength than with soldering or welding processes, since in the latter cases, constituents which are foreign to the substrate penetrate into the material separation 4 as a result of the soldering or welding additions. This is not the case when using electrolytic deposition.

In this case, material of the substrate 1 or layer 1 or material which has similar properties can be used.

The deposition process in the material separation 4 can optionally be improved by additional ultrasound excitation by means of at least one ultrasound probe 19, which is operated by an ultrasound source 22, in the electrolyte 10. The ultrasound excitation inter alia effects continuous mixing of the electrolyte 10, so that there are no inhomogeneities in the electrolyte 10 and its constituents. Furthermore, porous parts of a layer formed by the filling material are cavitationaly removed by the effect of the ultrasound waves.

A further improvement of the method can preferably be achieved by the use of pulsed currents.

Furthermore, the method can be improved by an eddy-current probe 16 being arranged in the region of the material separation 4, for example being placed on top of it, producing a corresponding interaction volume 28 in the substrate 1 around the material separation 4, i.e. the interaction volume 28 is mechanically excited, i.e. generates oscillations in the substrate 1.

The eddy-current probe 16 surrounds, for example, the opening 43 of the material separation 4 at the surface 2 toward the electrolyte 10, but does not cover this opening. The eddy-current probe 16 is operated by a controllable eddy-current generator 13. The depth of penetration  $\delta$ , i.e. the depth to which the interaction volume 28 extends into the substrate 1 from the surface 2, is given by the following formula:

$$\delta = \frac{503}{\sqrt{f\sigma\mu_r}}$$

in which  $f$  is the frequency of the eddy-current,  $\sigma$  is the conductivity of the substrate 1 and  $\mu_r$  is the permeability constant of the substrate/layer 1.

Therefore, the depth of penetration  $\delta$  and the interaction volume 28 can be set by means of the frequency  $f$ .

Figure 2 shows how a first material separation 4 in a substrate 1 can be filled in an improved way.

First of all, a region M1 in the region of the end 34 of the crack is surrounded, by suitable selection of the frequency  $f_1$ , so that the interaction volume 28 surrounds the region M1 while M1 is being filled.

In a second step, a second region M2 is filled with material, with the frequency  $f_2$  being selected in such a way that the interaction volume 28 only extends as far as the region M1 which has previously been filled or if appropriate only partially surrounds it.

Further regions M3, M4, ... as far as a surface 2 are filled with material by continuously increasing the frequency ( $f_3$ ,  $f_4$ , ...).

Of course, it is also possible for the frequency  $f$  to be continuously matched to the remaining depth of the material separation.

Taking account of the altered conductivity in the interaction volume 28, automatic control of the process is possible, since the filling material in the material separation 4 changes the conductivity of the substrate 1 in the interaction volume 28, which is measured and used for control purposes.

Figure 3 shows a time profile of the current of the voltage source 25. This may be formed from currents which are pulsed or varied over the course of time and can be repeated periodically.

The current is primarily composed of cathode components (substrate 1) and anode components (electrode 7). The pulse duration  $t_{on}$  during which a current  $I$  is flowing, the interpulse period  $t_{off}$  between the pulses 40 and a maximum intensity of the current  $I_{max}$  can be varied. It is also possible to alter the shape 37 of the current signal. All the parameters ( $I_{max}$ ,  $t_{off}$ ,  $t_{on}$ , ...) may be a function of time and can be repeated periodically in order to optimize the method.

An alloy (for example NiAl) is deposited by the individual constituents alternately being deposited to an increased extent.

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By way of example, for each individual alloying constituent Ni, Al there are different optimum parameters ( $I_{\max}$ ,  $t_{\text{off}}$ ,  $t_{\text{on}}$ , ...), which means that, for example, a first current pulse 40 is optimum for the element nickel (ion in the electrolyte 10) and the second,

subsequent current pulses 40 are optimum for aluminum. Even during the current pulse which is matched to one element, the other element is still being deposited, albeit to a lesser extent.

The pulses are constantly repeated, so that the constituents of the alloy are optimally mixed.

The proportion by weight of one alloying constituent in the material separation can be set by means of the pulse duration.

Figure 4 shows an example of a series of current pulses 40 which are repeated.

A sequence 34 comprises at least two blocks 77. Each block 77 comprises at least one current pulse 40.

A current pulse 40 is characterized by its duration  $t_{on}$ , the intensity  $I_{max}$  and its shape 37 (square-wave, delta-wave, ...). The interpulse periods between the individual current pulses 40 ( $t_{off}$ ) and the interpulse periods between the blocks 77 are equally important process parameters.

The sequence 34 comprises, for example, a first block 77 of three current pulses 40, between each of which there is an interpulse period. This is followed by a second block 77, which has a higher current intensity and comprises six current pulses 40. This is followed, after a further interpulse period, by four current pulses 40 in the reverse direction, i.e. with a changed polarity.

The sequence 34 is concluded by a further block 77 of four current pulses.

The sequence can be repeated a number of times.



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The individual pulse times  $t_{on}$  are preferably of the order of magnitude of approximately 1 to 10 milliseconds. The total duration of the block 77 is of the order of magnitude of up to 10 seconds, which means that up to 500 pulses are emitted in one block 77.

It is optionally possible to apply a low potential (base current) both during the pulse sequences and during the interpulse periods.

This prevents the electrodeposition from being interrupted, which can cause inhomogeneities.

The parameters of a block 77 are matched to one constituent of an alloy which is to be deposited, for example in order to optimize the deposition of this constituent. These parameters can be determined in individual tests. By way of example, the level of the constituents of the alloy in the layer to be applied can be defined by the duration of the individual blocks 77 in order, for example, to produce gradients in the layer. This is done by correspondingly lengthening or shortening the duration of the block 77 which is optimally matched to one constituent of the alloy.

Figure 5 shows a widened material separation 4.

To improve the deposition, the material separation 4 is widened before being filled. This can be done by drilling, EDM or other methods in order, for example, to increase the diameter.

The dashed line shows the material separation 4 prior to the widening.

# Patent Claims

1. A method for filling material separations at a surface of a substrate or a layer, characterized in that the material separation (4) is filled electrolytically in a first method step, with one or more eddy-current probes (13), which generate oscillations in the region around the material separation (4), being used in the region of the material separation (4).

2. The method as claimed in claim 1, characterized in that the substrate (1) or the layer (1) is electrically connected to an electrode (7), substrate or layer (1) and electrode being arranged in an electrolyte (10), and in that a current between substrate (1) and electrode (7) can be varied over the course of time.

3. The method as claimed in claim 2, characterized in that the current is pulsed.

4. The method as claimed in claim 2 or 3, characterized in that the parameters of the current (maximum current intensity ( $I_{\max}$ ), interpulse period ( $t_{\text{off}}$ ) and pulse duration ( $t_{\text{on}}$ ) and pulse shape (37)) are matched to the electrolyte (10).

5. The method as claimed in claim 2, characterized in that at least one ultrasound probe (19) is operated in the electrolyte (10).

6. The method as claimed in claim 1, characterized in that the frequency (f) of the eddy-current probe (16) is varied during the method.

7. The method as claimed in claim 6, characterized in that the frequency (f) is matched to the depth of the material separation (4).

8. The method as claimed in claim 2, characterized in that the electrolyte (10) includes material of the same type or a similar type to the material of the substrate (1) or the layer (1).

9. The method as claimed in claim 1, characterized in that the material separation (4) is widened in a first method step.

10. The method as claimed in claim 1, characterized in that a current/voltage pulse (40) is used for the electrolytic deposition, with both positive and negative current/voltage pulses (40) being used.

11. The method as claimed in claim 1, characterized in that a plurality of repeated current/voltage pulses (40) which are combined in a sequence (34) are used for the electrolytic deposition, the sequence (34) of at least two different blocks (77) being used, with a block (77) comprising at least one current pulse (40).

12. The method as claimed in claim 11, characterized in that a block (77) is determined by a number of current pulses (40), pulse duration ( $t_{on}$ ), interpulse period ( $t_{off}$ ), current intensity ( $I_{max}$ ) and pulse shape (37).

13. The method as claimed in claim 11, characterized in that a block (77) is in each case matched to a constituent of an alloy, in order to boost the deposition of this constituent of the alloy.

14. The method as claimed in claim 1, characterized in that an alloy of the type MCrAlY is deposited, in which M is an element selected from the group consisting of iron, cobalt or nickel.

15. The method as claimed in claim 11, characterized in that gradients are produced in the material composition within the material separation (4).

16. The method as claimed in claim 3 or 11, characterized in that a base current is superimposed on the current pulses (40) and/or the interpulse periods.

17. An apparatus for filling material separations at a surface of a substrate or a layer, characterized in that the apparatus (40) includes

a vessel (46) containing an electrolyte (10),

a voltage source (25),

at least one electrode (7) and

at least one eddy-current probe (16),

which can be placed on the substrate (1) or layer (1).

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18. The apparatus as claimed in claim 17, characterized in that the apparatus (40) has at least one ultrasound probe (19) which is arranged in the electrolyte (10).

FIG 1

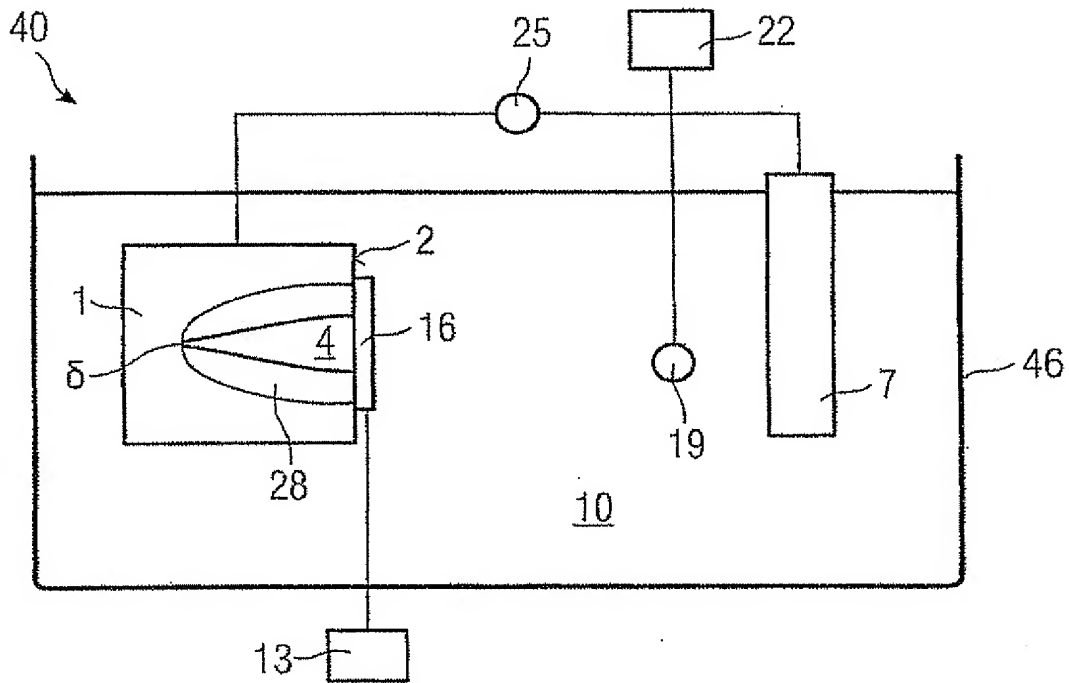


FIG 2

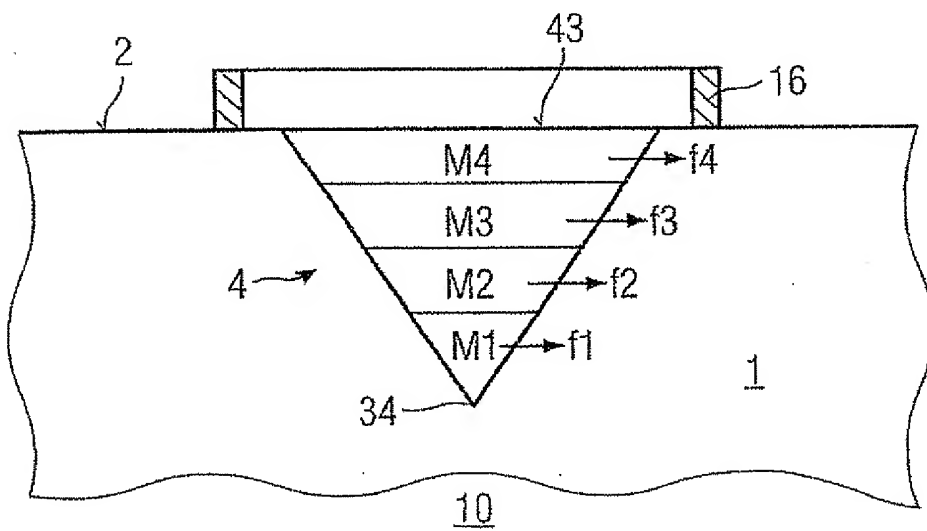




FIG 3

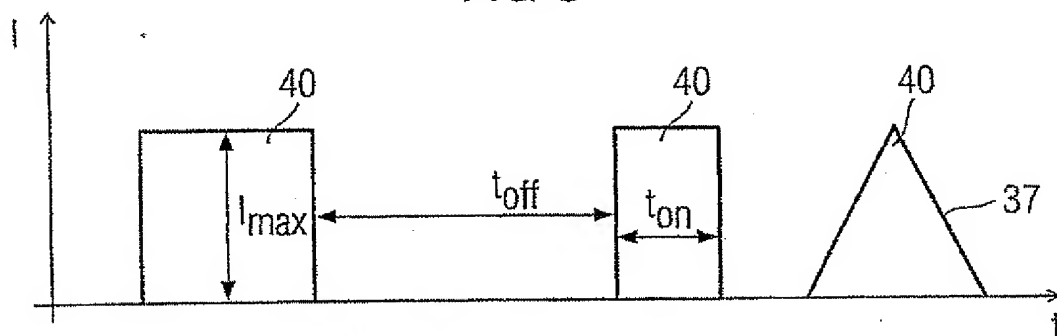


FIG 4

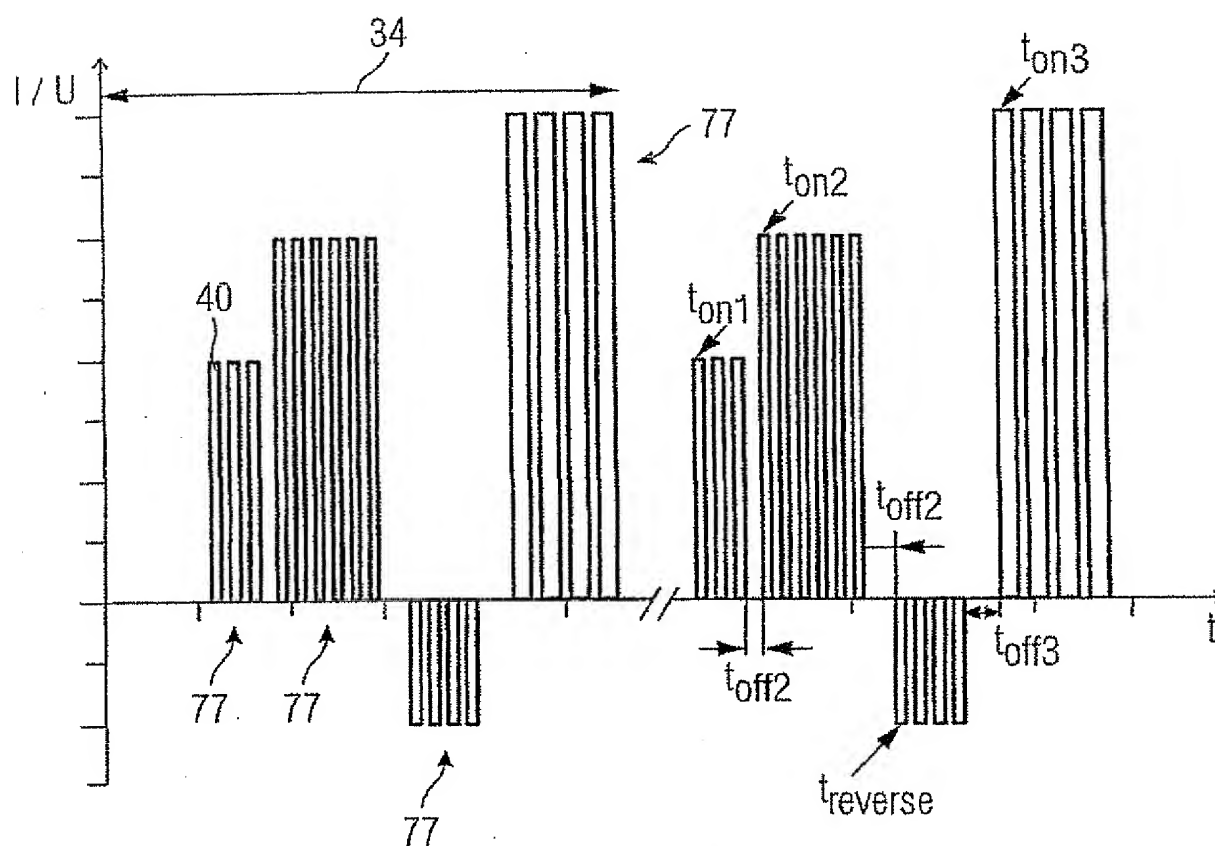


FIG 5

